AN INVESTIGATION OF FRICTION M. I. T. FOUR STROKE GEOMETRICALLY SIMILAR ENGINES

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AN INVESTIGATION OF FRICTION

IN M. I. T. FOUR STROKE

GEOMETRICALLY SIMILAR ENGINES

by

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Peter J.F. O'Reilly Lt (jg) U.S.N.

Submitted in Partial Fulfillment of the Requirements for the Degree of Naval Engineer from the Massachusetts Institute of Technology.

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ABSTRACT

AN INVESTIGATION OF FRICTION IN M.I.T.

FOUR STROKE

GEOMETRICALLY SIMILAR ENGINES

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Submitted for the degree of Naval Engineer in the Department of Naval Architecture and Marine Engineering on May 18,1951.

Three Geometrically Similar Engines are installed in Sloan Laboratory for the purpose of investigating the effect of size on engine characteristics and performance.

A theory has been formulated, which states that in similar engines operating at the same piston speed, if the ratio of oil viscosity to bore (characteristic dimension) is the same for all engines, then IMEP, FMEP, BMEP, and indicated thermal efficiency will be the same.

Previous investigative work on the GS engines has resulted in poor correlation of FMEP firing and but slightly better correlation in FMEP in the motoring condition.

The purpose of this thesis was to motor the engines in several stages of assembly, to systematically determine the mechanical friction contribution of each engine part. These results were then compared for the three engines in an effort to determine the source of disagreement.

This work finds that within the limits of experimental accuracy the motoring FMEP and MMEP do conform to theory. The data collected on the smallest of the three engines is at variance with that previously obtained, and essentially resolves the past disagreement with the theory.

The presence of a contact type rubber oil seal may contribute as much as 20% of the total friction mean effective pressure motoring in the completely assembled condition.

It is recommended that more firing data be collected to check previous information on firing FMEP and that the contact type oil seals be replaced with non-contact seals.

15597

May 18, 1951

Professor J. C. NEWELL
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Professor NEWELL:

In compliance with the requirements for the Degree of Naval Engineer from the Massachusetts Institute of Technology, we hereby submit a thesis entitled, "An Investigation of Friction in M.I.T. Four Stroke Geometrically Similar Engines."

A C K N O W L E D G M E N T

The authors wish to acknowledge their indebtedness for the helpful advice and criticisms given by:

Professor C. F. Taylor

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Mr. J. C. Livengood

Mr. D. S. Doremus

Mr. W. Hall

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ABBREVIATIONS AND SYMBOLS

BMEP	Brake Mean Effective Pressure
C	Bearing Clearance
D	Diameter
d'	Absolute Water Flow Manometer Scale Reading - Inches of Mercury
d	d' minus Scale Zero
F	Degrees Fahrenheit
FMEP	Friction Mean Effective Pressure
GSE	Geometrically Similar Engine
h'	Absolute Dynamometer Scale Reading - Inches of Mercury
h	h' minus Scale Zero
k	Dynamometer Scale Constant
l	Characteristic Dimension
MEP	Mean Effective Pressure
MMEP	Mechanical Mean Effective Pressure
N	Engine Speed - Rev. per Minute
PMEP	Pumping Mean Effective Pressure
RPM	Rev. per Minute
S	Stroke - Ft.
s	Piston Speed - Ft. per Minute
T_1	Temperature of Cooling Water at Inlet - Mercury Thermometer
T_2	" " " " at Outlet - " "
T_4	" " Circulating Oil at Sump Discharge - Mercury Thermometer
T_5	" " Bearing Oil at Inlet
T_7'	" " Main Bearing, Uncorrected - Thermocouple
T_7	" " " " , Corrected - "
T_8'	" " Cylinder Wall, Uncorrected - "
T_8	" " " " , Corrected - "

ABBREVIATIONS AND SYMBOLS cont'd

μ	Absolute Viscosity
V	Displacement Volume
A	Complete Engine - No Inlet or Exhaust Pipes
A*	Complete $2\frac{1}{2}$" Engine - Shaft Oil Seal Removed
B	Crankshaft, Rod, and Piston
B'	Crankshaft, Rod, and Piston - Before Alterations $2\frac{1}{2}$" Engine
C	Crankshaft and Idler.

INTRODUCTION

Three geometrically similar internal combustion engines, designed and constructed under the supervision of the Automotive Division of the Mechanical Engineering Dep't of the Massachusetts Institute of Technology were installed in Sloan Laboratory during 1947. These engines were built primarily for laboratory investigation of theoretical similitude relations concerning piston engines. The establishment of a general geometrically similar engine theory offers attractive possibilities in developing a basis for rational engine design, as contrasted to wholly empirical engine design. It could also permit of wider application of use of model or small scale engines in determining characteristics of large machines.

GSE Theory states that in G.S. engines operating at the same piston speed, IMEP, FMEP and BMEP must be the same for all engines, if the ratio of absolute oil viscosity to a characteristic dimension is the same for all engines (5).

The only previous work which has been accomplished on these engines was that of Gaboury et al (1), Breed and Cowdrey (2), Lobdell and Clark (3), and Mikel and McSwiney (4). The thesis by Gaboury et al indicated that IMEP in the three engines operating at the same piston speed conformed quite closely to predicted results. However the measured BMEP did not agree with theory due to variations in FMEP. Gaboury's work included both firing and motoring runs and showed somewhat better agreement in the motoring condition than when firing.

The purpose of this investigation is to determine the mechanical friction contribution of the major components of each engine to the FMEP in motoring condition. It was hoped that such data might provide an understanding of the reason for the variation of FMEP between the three engines. Also it would serve to check previous work.

EQUIPMENT

The three engines under discussion are single cylinder, four stroke, spark ignition machines of 2½, 4, and 6 inch bore. All engine dimensions and accessory equipment are proportioned in the same ratio as the bores (5). Dynamometers on the 2½ and six inch engines are of the alternating current drive type with Dynamatic magnetic speed control clutches. The 4 inch engine is equipped with a conventional direct current dynamometer. All machines are equipped with a sensitive hydraulic torque measuring device (7). Each engine is installed in an individual test cell mounted on a spring-supported bed plate complete with inlet surge tank, vaporizing tank and exhaust surge tank. Cooling water is circulated by a separate pump, and temperature controlled through a steam jacketed heat exchanger. A circulating oil pump is provided for a high velocity oil circuit through the crankcase and heat exchanger. This provides close and homogenous temperature control of the lubricating oil. An additional oil pressure pump is installed for bearing and cylinder lubrication. Oil and water circuits are fitted with direct-reading thermometers. A thermocouple is installed at the main bearing surface in each engine. A diagrammatic sketch of the equipment and arrangement may be found in Appendix "A".

PROCEDURE

Each engine was motored in three different conditions of assembly, as described below and shown by sketch in Appendix "B".

Condition "A": Engine completely assembled. Friction elements are two main bearings, crank journal, piston and rings, timing gear drive yoke bushing, main oil seal, timing gears and bushings, camshaft bearings, cam followers and valves. No inlet and exhaust pipes were fitted, nor was the ignition equipment.

Condition "B": Crankshaft, cylinder, piston and connecting rod installed. No cylinder head, camshaft gear or valve pushrods. Friction elements are as in Condition "A" without idler gear and valve train.

Condition "C": Crankshaft and idler gear installed. No cylinder, piston, connecting rod or camshaft gear. Friction elements are two main bearings, timing gear drive yoke bushing, timing pinion, idler gear and the main oil seal. On these runs an aluminum sleeve was placed over the crank journal to prevent loss of oil pressure.

In each condition the engines were operated over a speed range from zero to 1680 feet per minute piston speed. Oil temperatures were held constant at 150° F., circulating water inlet at 180° F., circulating water flow rate was held constant at one value of flow per unit area. In collection of all data sufficient time was allowed for equilibrium conditions to prevail. A series of readings were observed at each run to show systematically that conditions were substantially constant.

In previous work on the engines, no attempt had been made to measure or regulate the jacket water flow rate. For this investigation A.S.M.E. square edged standard orifices were inserted into the water circulation system and calibrated. The first work conducted on the $2\frac{1}{2}$" engine then consisted of a series of runs to determine what effect, if any, variation

in coolant flow rate would have on engine friction results. On all subsequent runs a water flow of .024 /sec./in.^{2} was arbitrarily used.

In concluding the first series of high speed runs on the 2$\frac{1}{2}$" engine in "B" condition, a sudden change in friction and bearing temperature measurements indicated the possibility of a bearing derangement. The engine was dismantled and flaking off of the babbitt in the outer main bearing was discovered. Previous difficulty had been experienced with these bearings in that the very thin babbitt layer (.005") had not been fully bonded to the backing material. Several attempts at manufacture of new bearings also resulted in poor babbitt bond, so both main bearings on this engine were changed using solid phosphor bronze as the bearing material. Investigation of bearing clearances at this time showed that the connecting rod bearing clearance was not as specified by similitude requirements. To rectify this a bronze conrod bearing was installed with clearance increased from .001" to .0025". Therefore when the 2$\frac{1}{2}$" engine was returned to service all three principle bearings had been changed to bronze with increased clearance in the connecting rod bearing.

Early in the investigation, in using the magnetically-coupled type of dynamometer it was noticed that the hydraulic torque-scale zero reading varied appreciably depending upon whether the zero was set with the dynamometer motor running or with the entire machine shut down. By disconnecting the dynamometer output shaft from the engine, it was determined that some form of drag existed in the magnetic coupling even with no excitation on. As a result all scale zeroes were set with the dynamometer completely off. A small possible error was also detected as related to the cooling water flow through the dynamometer. Insofar as cooling water is required for normal operation, this valve was left open when setting the scale zero.

At every opportunity measurements were taken of principal engine parts and recorded in Appendix [illegible]. The 2[illegible]" engine rings were found to have considerably more relative spring tension than the other two engines and were subsequently modified to conform more closely with similitude requirements.

After completing all other experimental runs, the main oil seal was removed from the 2[illegible]" engine and the engine run in the "[illegible]" condition to determine the magnitude of the friction contribution of this oil seal.

RESULTS

The observations resulting from this investigation are contained in the subsequent data sheets. The smooth data is plotted in Figures 1 to 8. Fig. 1 shows the results obtained on the $2\frac{1}{2}$" engine with systematically varied cooling water flow rates. All other mechanical mep curves are for constant cooling water rate, and constant inlet oil and water temperatures. For purposes of easy comparison these data were plotted first for each engine in three different conditions of assembly, and again for each condition of assembly for the three different engines.

DISCUSSION

This investigation involved the first attempt to correlate the rate of cooling water flow between the three engines. After calibrating flow orifices, it was intended that each engine be run with equal flow per unit area. At the start of the work on the $2\frac{5}{8}$" engine it became a matter of interest to determine any possible variation in friction as a function of coolant flow. Therefore runs were made at five different flow rates and the results plotted in Fig. 1. This curve shows no significant variation in mechanical mean effective pressure that can be attributed to flow rate alone. All other friction runs were then run at constant coolant flow rate per unit area.

Fig. 2 shows the results obtained on the $2\frac{5}{8}$" engine. The results that were obtained in the "B" Condition both before and after dismantling the engine for new bearings are plotted in Fig. 9. No significant change in friction occurred after changing both main and conrod bearings from babbitt to bronze, increasing the conrod clearance and reducing the relative ring tension by more than one-half. The curves of Fig. 8 in the "A" Condition both with and without the oil seal show that this seal contributes a large proportion of the total friction particularly at low speeds where the seal probably operated largely in the boundary region of fluid friction. The complete engine or "A" Condition curve is significantly lower than that obtained by Saboury et al, but it must be emphasized that in this investigation the engines were run without inlet and exhaust surge tanks or piping, so that the pumping contribution of Saboury's curve cannot be compared on an identical basis.

Figure 3 is the result for the 4" engine. On this machine the "A" Condition curve is somewhat closer to Saboury et al than on the $2\frac{5}{8}$" engine. Figure 4 is the plotted data for the 6" engine. The trends are comparable to the 4" machine.

Figure 5 is the result for the three engines in the "A" or complete engine condition. These curves show definitely that within the range of experimental error the motoring FMEP is the same for all engines.

Figure 6 is the same for the "B" condition, and also shows that mechanical mean effective pressure for the three engines is the same within the limits of experimental accuracy.

Figure 7 is the "C" or bare-crankshaft condition of operation. These curves show a somewhat greater spread than conditions "B" and "A".

Figure 8 compares the friction developed in the 2½" engine with and without the main oil seal. The friction contribution of this seal is large, particularly at low speed where the seal may operate largely in the boundary realm of fluid friction. It is manifestly difficult to design and obtain this type of seal on any basis that would guarantee geometric similitude. Among the variants would be rubber hardness, area of contact, the change of rubber properties with time and of course surface characteristics of the shaft. Note that the maximum friction contribution of the seal in the 2½" engine is approximately one-half the total for the "C" or bare-crankshaft condition. It was also noted that in running without the oil seal the equilibrium temperatures of the main bearing were considerably lower than in the comparable condition with seals installed. A correction for oil viscosity might then magnify the difference between these two curves.

It was considered by the authors throughout the experimental work that the accuracy of reading the hydraulic scale was about .7 FMEP (.2" mercury scale reading) varying slightly between engines.

A possible cause of disagreement with similar engine theory lies in the inherent difficulty of satisfying the requirement that μ_l be the same in all engines (See Appendix "B"). Assuming that the viscosity-temperature characteristics of the three lubricating oils used would be similar, it is not likely

that the temperatures at the friction surfaces would be the same in all the engines. Still another cause for departure from theory is the fact that real bearings do not operate under the assumptions involved in the classical theory (Petroff) of lubrication, upon which the similar engine theory is based.

CONCLUSION

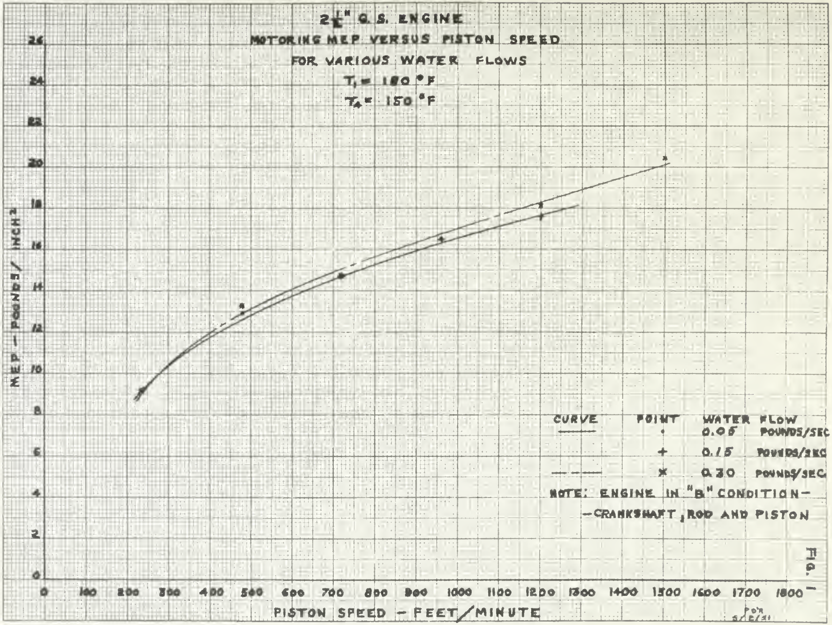
The conclusions arising from the data of this investigation are as follows:

1. The theory, which predicts that the [illegible] and [illegible] of similar engines operating at the same piston speed will be the same, is a valid one, for engines under motoring conditions.
2. The use of a contact type oil seal may introduce large friction forces and is a component of uncertain behaviour in experimental engines of this type.
3. The effect of cooling water velocity on [illegible] is negligibly small for motoring conditions.

RECOMMENDATIONS

In view of the strong diversity between the motoring FMEP obtained by Jasoury et al and the "A" condition results of this investigation, it is recommended that more firing data be collected on the 2½" engine to (1) check previous data or (2) determine if the changes made on the engine during this investigation will have any effect upon FMEP firing.

The rubber contact type oil seals in all three engines should be replaced by a non-contact oil seal. If this is undertaken another series of motoring data should be collected to compare with the results of this thesis.



2 1/2" G.S. ENGINE
MOTORING MEP VERSUS PISTON SPEED
FOR VARIOUS WATER FLOWS
T_1 = 180 °F
T_4 = 150 °F
MEP – POUNDS/INCH²
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
PISTON SPEED – FEET/MINUTE
CURVE
POINT
WATER FLOW
0.05 POUNDS/SEC
0.15 POUNDS/SEC
0.30 POUNDS/SEC
NOTE: ENGINE IN "B" CONDITION–
–CRANKSHAFT, ROD AND PISTON

FIG. 1

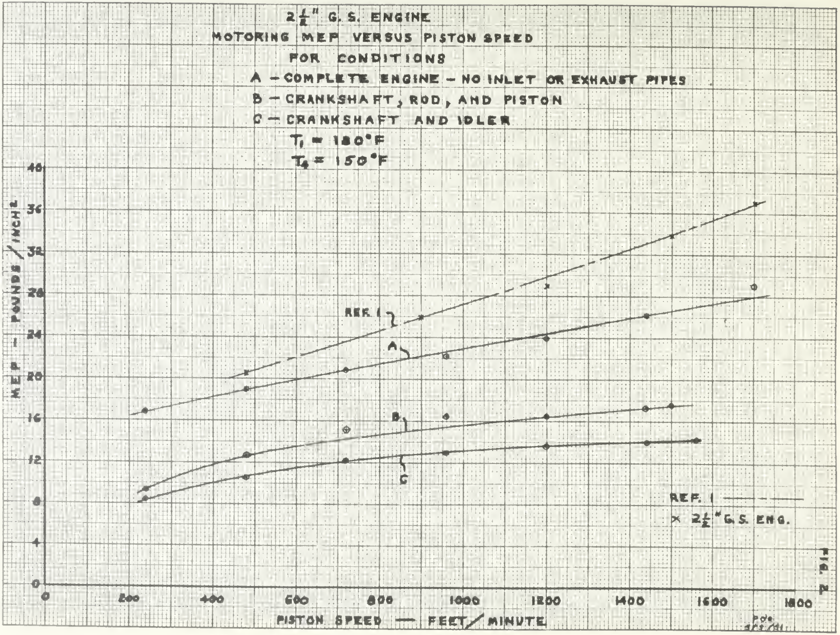

2 1/2" G. S. ENGINE
MOTORING MEP VERSUS PISTON SPEED
FOR CONDITIONS
A – COMPLETE ENGINE – NO INLET OR EXHAUST PIPES
B – CRANKSHAFT, ROD, AND PISTON
C – CRANKSHAFT AND IDLER
T_1 = 180°F
T_4 = 150°F
MEP – POUNDS / INCH²
0
4
8
12
16
20
24
28
32
36
40
REF. 1
A
B
C
REF. 1
× 2 1/2" G. S. ENG.
0
200
400
600
800
1000
1200
1400
1600
1800
PISTON SPEED — FEET / MINUTE

FIG. 2

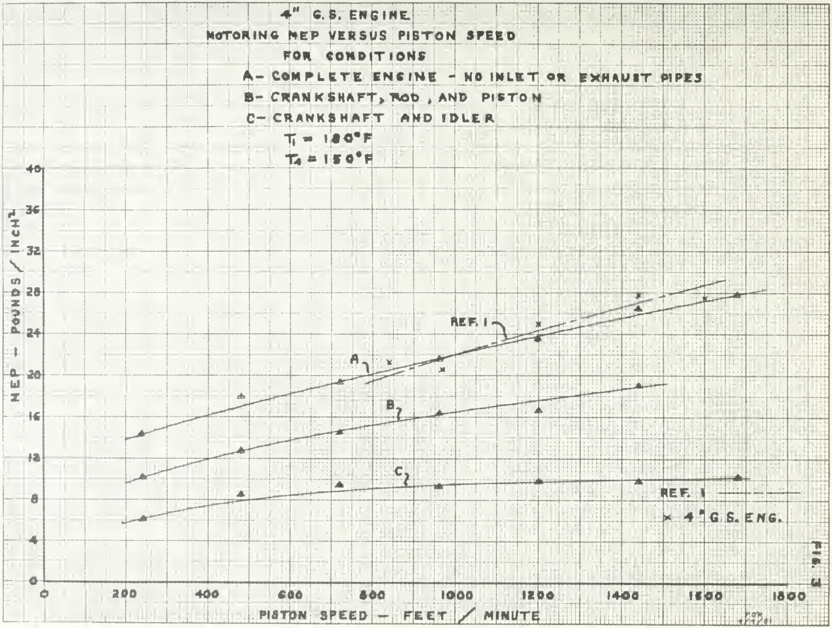
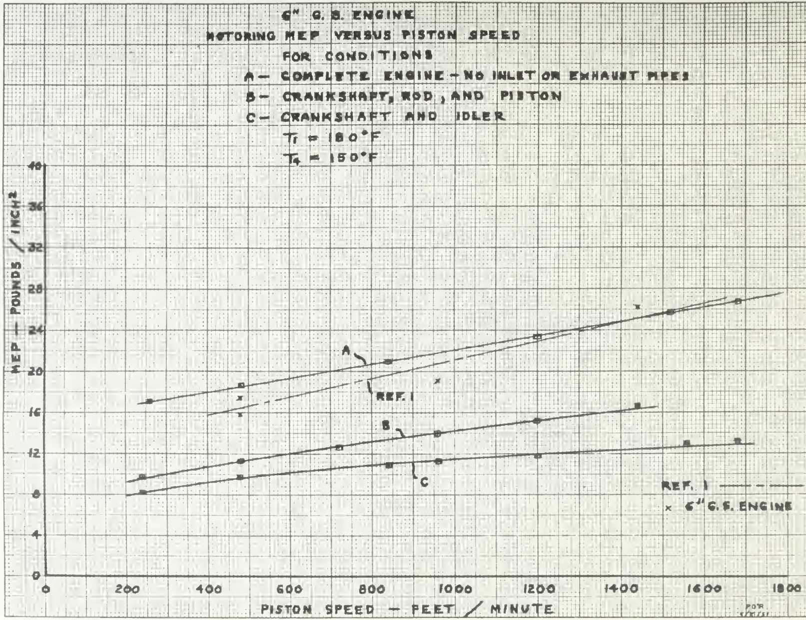

4" G.S. ENGINE
MOTORING MEP VERSUS PISTON SPEED
FOR CONDITIONS
A- COMPLETE ENGINE - NO INLET OR EXHAUST PIPES
B- CRANKSHAFT, ROD, AND PISTON
C- CRANKSHAFT AND IDLER
T_1 = 180°F
T_4 = 150°F
MEP - POUNDS / INCH²
PISTON SPEED - FEET / MINUTE
0
4
8
12
16
20
24
28
32
36
40
0
200
400
600
800
1000
1200
1400
1600
1800
A
B
C
REF. I
REF. I
× 4" G.S. ENG.

FIG. 3



6" G. S. ENGINE
MOTORING MEP VERSUS PISTON SPEED
FOR CONDITIONS
A — COMPLETE ENGINE - NO INLET OR EXHAUST PIPES
B — CRANKSHAFT, ROD, AND PISTON
C — CRANKSHAFT AND IDLER
T_1 = 180°F
T_4 = 150°F
MEP — POUNDS / INCH²
0
4
8
12
16
20
24
28
32
36
40
A
REF. I
B
C
REF. 1
× 6" G. S. ENGINE
0
200
400
600
800
1000
1200
1400
1600
1800
PISTON SPEED — FEET / MINUTE

FIG. 4

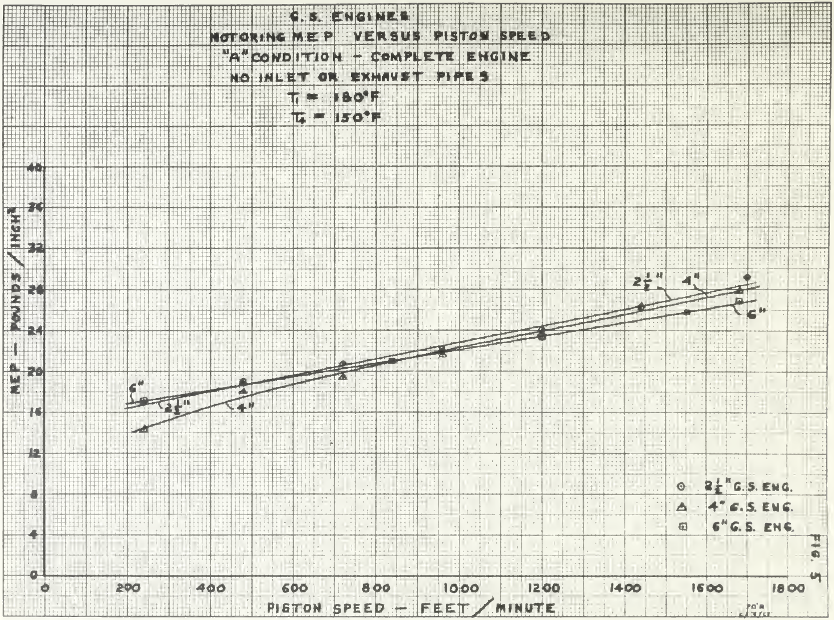
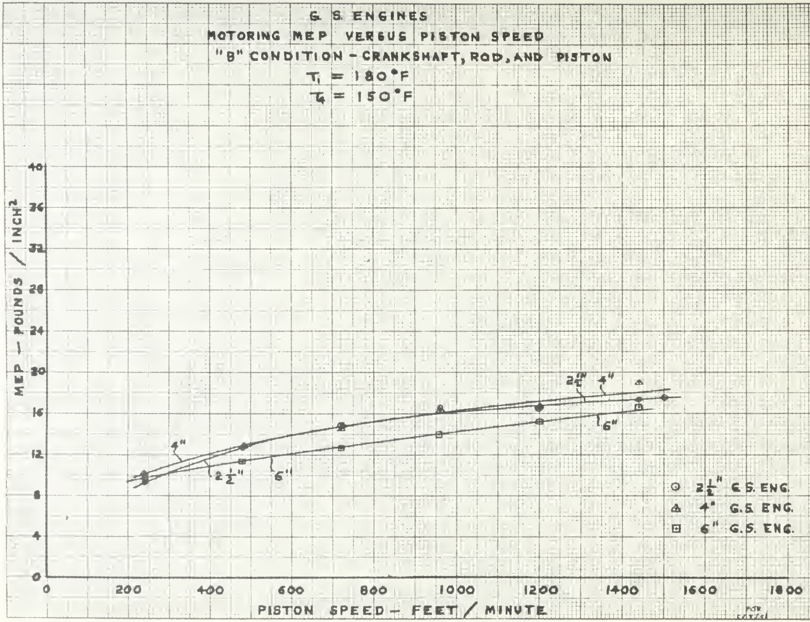

G. S. ENGINES
MOTORING M.E.P. VERSUS PISTON SPEED
"A" CONDITION - COMPLETE ENGINE
NO INLET OR EXHAUST PIPES
T1 = 180°F
T4 = 150°F
MEP — POUNDS / INCH²
0
4
8
12
16
20
24
28
32
36
40
0
200
400
600
800
1000
1200
1400
1600
1800
PISTON SPEED — FEET / MINUTE
6"
2½"
4"
2½ "G.S. ENG.
4" G.S. ENG.
6" G.S. ENG.

FIG. 5


G. S. ENGINES
MOTORING MEP VERSUS PISTON SPEED
"B" CONDITION - CRANKSHAFT, ROD, AND PISTON
T_1 = 180°F
T_4 = 150°F
MEP — POUNDS / INCH²
0
4
8
12
16
20
24
28
32
36
40
0
200
400
600
800
1000
1200
1400
1600
1800
PISTON SPEED — FEET / MINUTE
4"
2 1/2"
6"
2 1/2"
4"
6"
2 1/2" G.S. ENG.
4" G.S. ENG.
6" G.S. ENG.
FIG. 6

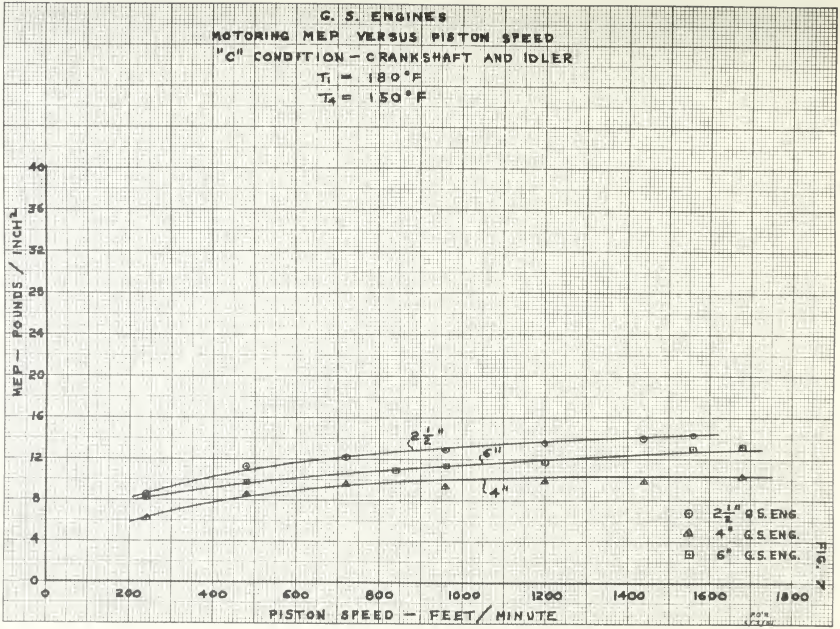

G. S. ENGINES
MOTORING MEP VERSUS PISTON SPEED
"C" CONDITION – CRANKSHAFT AND IDLER
T_1 = 180°F
T_4 = 150°F
MEP – POUNDS / INCH²
0
4
8
12
16
20
24
28
32
36
40
0
200
400
600
800
1000
1200
1400
1600
1800
PISTON SPEED – FEET / MINUTE
2 1/2"
6"
4"
2 1/2" G.S. ENG.
4" G.S. ENG.
6" G.S. ENG.

FIG. 7

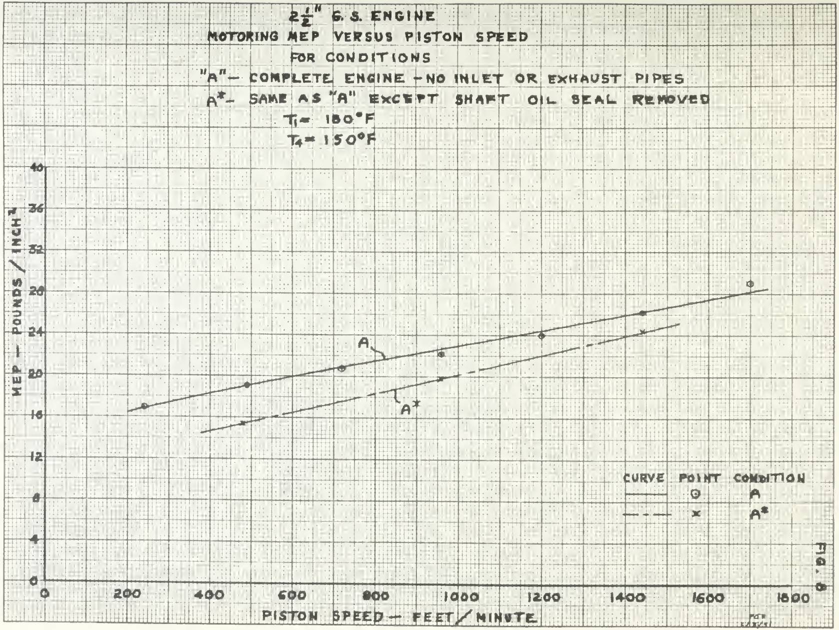

2 1/2" G. S. ENGINE
MOTORING MEP VERSUS PISTON SPEED
FOR CONDITIONS
"A" – COMPLETE ENGINE – NO INLET OR EXHAUST PIPES
A* – SAME AS "A" EXCEPT SHAFT OIL SEAL REMOVED
T1 = 180°F
T4 = 150°F
MEP — POUNDS / INCH²
PISTON SPEED — FEET / MINUTE
0
4
8
12
16
20
24
28
32
36
40
0
200
400
600
800
1000
1200
1400
1600
1800
A
A*
CURVE POINT CONDITION
A
A*

FIG. 8

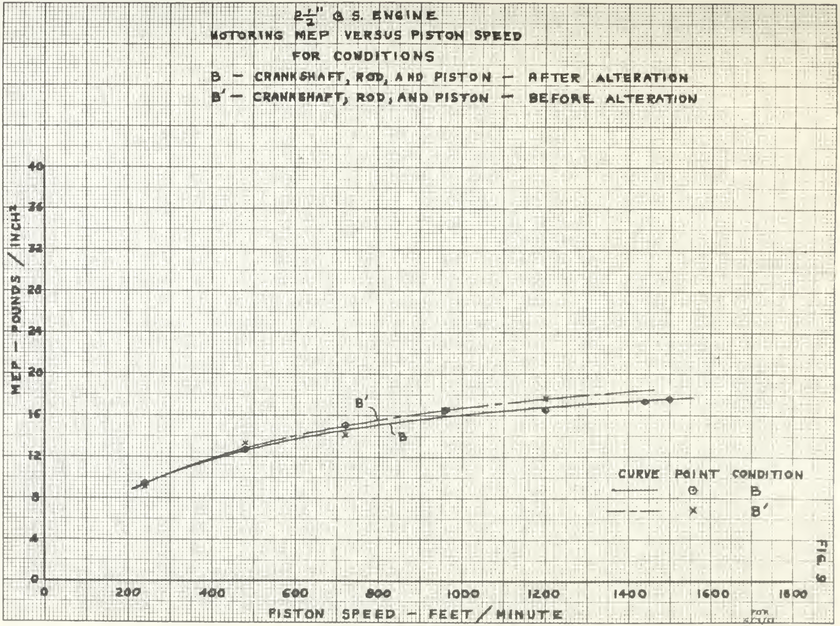

2 1/2" Q.S. ENGINE
MOTORING MEP VERSUS PISTON SPEED
FOR CONDITIONS
B — CRANKSHAFT, ROD, AND PISTON — AFTER ALTERATION
B' — CRANKSHAFT, ROD, AND PISTON — BEFORE ALTERATION
MEP — POUNDS / INCH²
PISTON SPEED — FEET / MINUTE
0
4
8
12
16
20
24
28
32
36
40
0
200
400
600
800
1000
1200
1400
1600
1800
B'
B
CURVE
POINT
CONDITION
B
B'

FIG. 9

TABLE I

$2\frac{1}{2}$" G.S. ENGINE
A-CONDITION - COMPLETE ENGINE
$T_1 = 180°F$ $T_4 = 150°F$

28 APRIL 1951

RUN	RPM	S	d'	d	h'	h	T_1	T_2	T_4	T_6	T_7'	T_7	T_8'	T_8	MEP	FINAL MEP
A-1	480	240	-3.9	6.1	5.1	4.9	178	178	148	146	120	121	178	180	17.6	
			-3.9	6.1	5.3	4.7	180	180	150	149	121	122	178	180	16.87	
			-3.9	6.1	5.3	4.7	180	180	151	151	127	128	178	180	16.87	16.87
A-2	960	480	-3.9	6.1	4.7	5.3	180	180	150	150	140	141	176	178	19.00	
			-3.9	6.1	4.7	5.3	180	180	150	150	141	142	177	179	19.00	19.00
A-3	1440	720	-3.9	6.1	4.2	5.8	180	180	150	150	154	155	181	183	20.80	
			-3.9	6.1	4.2	5.8	180	180	151	151	154	155	181	183	20.80	20.80
A-4	1920	960	-3.9	6.1	3.8	6.2	178	178	149	148	164	165	182	184	22.20	
			-3.9	6.1	3.8	6.2	180	180	150	150	164	165	183	185	22.20	
			-3.9	6.1	3.8	6.2	180	180	150	150	164	165	183	185	22.20	22.20
A-5	2400	1200	-3.9	6.1	3.2	6.8	180	180	152	152	175	177	186	188	24.40	
			-3.9	6.1	3.3	6.7	180	180	150	151	175	177	186	188	24.00	
			-3.9	6.1	3.3	6.7	180	180	150	150	175	177	186	188	24.00	24.00
A-6	2880	1440	-3.9	6.1	2.7	7.3	181	181	150	151	183	185	187	189	26.20	
			-3.9	6.1	2.7	7.3	180	181	151	153	184	186	187	189	26.20	
			-3.9	6.1	2.7	7.3	178	180	150	153	184	186	186	188	26.20	26.20
A-7'	3400	1700	-3.9	6.1	1.8	8.2	180	180	153	154	192	194	188	190	29.40	
			-3.9	6.1	1.8	8.2	180	181	151	154	193	195	189	191	29.40	
			-3.9	6.1	1.9	8.1	181	182	150	153	193	195	190	192	29.10	
			-3.9	6.1	1.9	8.1	181	182	150	152	193.5	196	190	192	29.10	29.10

NOTE: A-7' MAXIMUM SPEED RUN   d' SCALE ZERO AT -10.0   h' SCALE ZERO AT 10.0

SAMPLE CALCULATION

$2\frac{1}{2}$" G.S. ENGINE   RUN A-1   28 APRIL 1951

$$k \times h = MEP$$
$$3.59 \times 4.9 = 17.6 \text{ P.S.I.}$$

h = SCALE READING
k = DYNAMOMETER SCALE CONSTANT

DYNAMOMETER SCALE CONSTANTS

ENGINE	k
$2\frac{1}{2}$"	3.59
4"	3.28
6"	3.89

TABLE II

$2\frac{1}{2}$" G.S. ENGINE

A^* CONDITION – COMPLETE ENGINE - SHAFT OIL SEAL REMOVED

$T_1 = 180°F$ $T_4 = 150°F$

1 MAY 1951

RUN	RPM	S	d'	d	h'	h	T_1	T_2	T_4	T_6	T_7'	T_7	MEP	FINAL MEP
A^*-4	1920	960	-3.9	6.1	4.4	5.6	184	184	152	150	144	145	20.10	
			-3.9	6.1	4.5	5.5	185	185	152	151	146	147	19.75	
			-3.9	6.1	4.5	5.5	183	183	152	150	146	147	19.75	19.75
A^*-6	2880	1440	-3.9	6.1	3.2	6.8	180	180	152	152	162	163	24.40	
			-3.9	6.1	3.2	6.8	178	178	148	147	165	166	24.40	
			-3.9	6.1	3.2	6.8	180	180	153	152	166	167	24.40	24.40
A^*-4	1920	960	-3.9	6.1	4.5	5.5	178	178	152	152	153	154	19.75	CHECK
A^*-2	960	480	-3.9	6.1	5.7	4.3	180	180	152	149	139	140	15.45	
			-3.9	6.1	5.7	4.3	180	180	152	149	139	140	15.45	15.45

d' SCALE ZERO AT -10.0

h' SCALE ZERO AT 10.0

TABLE III

$2\frac{1}{2}$" G. S. ENGINE

B' CONDITION – CRANKSHAFT, ROD AND PISTON – BEFORE ALTERATION

$T_1 = 180°F$ $T_4 = 150°F$

31 JANUARY 1951

RUN	RPM	S	d'	d	h'	h	T_1	T_2	T_4	T_6	T_7'	T_7	T_8'	T_8	MEP	FINAL MEP
B-13	480	240	-3.9	6.1	7.45	2.55	180	182	150	148	130.5	131.5	179	181	9.15	
			-3.9	6.1	7.40	2.60	180	182	160	148	130.5	131.5	179	181	9.34	
			-3.9	6.1	7.50	2.50	180	182	150	148	130.5	131.5	179	181	8.96	
			-3.9	6.1	7.40	2.60	180	182	150.5	148.5	130.6	131.5	179.5	181	9.34	9.20
B-11	480	240	-9.3	0.7	7.45	2.55	181	184	150	148	130.5	131.5	179.5	181	9.15	
			-9.3	0.7	7.40	2.60	180	182.5	160	148	131	132	178.0	180	9.34	
			-9.3	0.7	7.50	2.50	180	184	160	148	130.5	131.5	179.0	181	8.96	
			-9.25	0.75	7.45	2.55	180	183.5	150	148	130.5	131.5	179.0	181	9.15	9.15
B-21	960	480	-9.25	0.75	6.45	3.55	180.5	184	151	149	145	146	182.5	185	12.75	
			-9.25	0.75	6.35	3.65	180.0	183	150	148	144	145	181	183	13.10	
			-9.25	0.75	6.40	3.60	180.5	184	149.5	148	144.5	145.5	182	184	12.92	
			-9.25	0.75	6.40	3.60	180.0	183	150	148.5	144.	145	181	183	12.92	12.92
B-23	960	480	-3.85	6.15	6.30	3.70	181	182	151	150	143	144	182	184	13.29	
			-3.90	6.10	6.30	3.70	180	182	150.5	150	143	144	181	183	13.29	
			-3.75	6.25	6.30	3.70	178	179.5	160	149	143	144	179	181	13.29	
			-3.75	6.25	6.30	3.70	178	179	150	148.5	143	144	178	180	13.29	13.29
B-25	960	480	+12.5	22.6	6.30	3.70	180	182	149	147	143	144	181	183	13.29	
			+12.4	22.4	6.30	3.70	180.5	182	150	148	143	144	181	183	13.29	13.29
B-55	2400	1200	+12.6	22.6	4.95	5.05	179	180	151	150	177	179	183	186	18.13	
			+12.6	22.6	4.95	5.05	180	181	151	149.5	178	180	183	186	18.13	18.13
B-53	2400	1200	-3.9	6.1	5.10	4.90	181	183	150	149.5	179	181	186	188.5	17.60	
			-3.9	6.1	5.10	4.90	181	183	161	160	180	182	187	189.5	17.60	17.60
B-51	2400	1200	-9.2	0.8	5.15	4.85	180	183	150	148.5	180	182	188	191	17.41	
			-9.2	0.8	5.15	4.85	180	183	148	148	180	182	187	189.5	17.41	17.41
13 FEBRUARY 1951																
B-15	480	240	+12.0	22.0	7.4	2.6	182	183	152	150	128	130	179	180		
			+12.0	22.0	7.4	2.6	180	182	152	150	128	129	178	179		
			+12.0	22.0	7.45	2.55	180	181	151	150	128	129	177	178	9.22	
			+12.0	22.0	7.45	2.55	179	180	150	149	128	129	176	177	9.22	9.22
14 FEBRUARY 1951																
B-35	1440	720	+12.5	22.5	6.90	4.10	182	184	150	148	153	154	183	185	14.70	
			+12.5	22.5	5.90	4.10	180	182	152	150	154	155	182	184	14.70	
			+12.5	22.5	5.90	4.10	180	181	151	149	154.5	155	181	183	14.70	14.70

d' SCALE ZERO AT -10.0

h' SCALE ZERO AT 10.0

TABLE III (CONTINUED)

14 FEBRUARY 1951

RUN	RPM	S	d'	d	h'	h	T_1	T_2	T_4	T_6	T_7'	T_7	T_8'	T_8	MEP	FINAL MEP
B-33	1440	720	-3.6	6.4	5.90	4.10	180	180	150	148	156	157	181	183	14.70	
			-3.6	6.4	5.90	4.10	180	181	150	148	156	157	182	184	14.70	14.70
B-31	1440	720	-9.3	0.7	5.90	4.10	180	182	150	148	156	157	182	184	14.70	
			-9.3	0.7	5.90	4.10	180	181	150	149	156	157	180.5	183	14.70	14.70
19 FEBRUARY 1951																
B-41	1920	960	-9.1	0.9	5.40	4.60	178	185	150	148	165	166	180	182	16.50	
			-9.1	0.9	5.45	4.55	180	183	150	148	165	166	180	182	16.50	16.50
B-43	1920	960	-3.8	6.2	5.40	4.60	178	178	150	148	165.5	167	179	181	16.50	
			-3.8	6.2	5.40	4.60	180	181	150	148	165.6	167	180	182	16.50	16.50
B-65	3000	1500	+12.6	22.6	4.30	5.70	180	181	150	150	190	192	186	188	20.46	20.46

d' SCALE ZERO AT -10.0
h' SCALE ZERO AT 10.0

NOTE: IN RUN DESIGNATOR LETTER INDICATES CONDITION OF ASSEMBLY
FIRST NUMBER INDICATES SPEED
SECOND NUMBER INDICATES COOLING WATER FLOW RATE AS:

1 – 0.05 #/SEC
2 – 0.10 #/SEC.
3 – 0.15 #/SEC.
4 – 0.20 #/SEC.
5 – 0.30 #/SEC.

TABLE IV

$2\frac{1}{2}$" G. S. ENGINE

B CONDITION – CRANKSHAFT, ROD, AND PISTON – AFTER ALTERATION

$T_1 = 180°F$ $T_4 = 150°F$

27 APRIL 1951

RUN	RPM	s	d′	d	h′	h	T_1	T_2	T_4	T_6	T_7'	T_7	T_8'	T_8	MEP	FINAL MEP
B-1	480	240	-3.9	6.1	6.9	3.1	180	180	149	147	114	115	175	177	11.10	
			-3.9	6.1	7.25	2.75	180	180	150	149	123	124	176	178	9.88	
			-3.9	6.1	7.30	2.70	182	182	150	148	125	126	179	181	8.70	
			-3.9	6.1	7.40	2.60	181	181	150	148	127	128	179	181	9.35	
			-3.9	6.1	7.40	2.60	180	180	150	148	127	128	178	180	9.35	
			-3.9	6.1	7.40	2.60	160	180	150	148	127	128	178	180	9.35	9.35
B-2	960	480	-3.9	6.1	6.35	3.65	180	180	150	149	144	145	177	179	13.10	
			-3.9	6.1	6.35	3.65	180	180	151	149	145	146	177	179	13.10	
			-3.9	6.1	6.60	3.40	180	180	150	149	145	146	177	179	12.20	
			-3.9	6.1	6.60	3.40	180	180	150	149	144	145	177	179	12.20	
			-3.9	6.1	6.45	3.55	180	180	150	149	146	147	177	179	12.72	12.72
B-3	1440	720	-3.9	6.1	5.80	4.20	180	180	160	149	157	158	179	181	15.08	
			-3.9	6.1	5.70	4.30	180	180	150	149	158	159	178	180	15.42	
			-3.9	6.1	5.75	4.25	180	180	150	149	159	160	178	180	15.25	
			-3.9	6.1	5.80	4.20	180	180	150	149	159	160	178	180	15.08	15.08
B-4	1920	960	-3.9	6.1	5.30	4.70	179	179	150	150	173	175	180	182	16.88	
			-3.9	6.1	5.20	4.80	180	180	150	150	175	177	180	182	17.20	
			-3.9	6.1	5.30	4.70	180	180	160	150	167.5	170	181	183	16.88	
			-3.9	6.1	5.40	4.60	180	180	150	150	168	170	181	183	16.50	16.50
B-5	2400	1200	-3.9	6.1	5.10	4.90	181	180	150	150	183	185	183	185	17.60	
			-3.9	6.1	5.40	4.60	180	180	149	148	176	178	183	185	16.50	
			-3.9	6.1	5.40	4.60	180	180	150	150	172	174	180	182	16.50	
			-3.9	6.1	5.40	4.60	180	180	150	150	174	176	180	182	16.50	16.50
B-6	2880	1440	-3.9	6.1	5.20	4.80	178	178	151	151	180	182	182	184	17.22	
			-3.9	6.1	5.20	4.80	179	179	150	150	181	183	183	185	17.22	17.22
B-7′	3000	1500	-3.9	6.1	5.10	4.90	180	180	150	150	184	186	186.5	189	17.60	
			-3.9	6.1	5.10	4.90	180	180	150	150	184	186	186	188	17.60	17.60

NOTE: B-7′ MAXIMUM SPEED RUN

d′ SCALE ZERO AT -10.0
h′ SCALE ZERO AT 10.0

TABLE V

$2\frac{1}{2}$" G.S. ENGINE

C CONDITION - CRANKSHAFT AND IDLER

$T_1 = 180°F$ $T_4 = 150°F$

21 APRIL 1951

RUN	RPM	S	h'	h	T_4	T_6	T_7'	T_7	MEP	FINAL MEP
C*-2	960	480	7.0	3.0	154	150	116	117	10.77	
			7.1	2.9	148	146	132	133	10.40	
			7.1	2.9	150	149	133	134	10.40	10.40
C*-5	2400	1200	6.4	3.6	151	150	162	163	12.90	
			6.5	3.5	151	150	166	167	12.57	
			6.6	3.4	151	150	168	169	12.20	
			6.6	3.4	151	150	168	169	12.20	12.20

NOTE: IN C* CONDITION IDLER WAS REMOVED

RUN	RPM	S	h'	h	T_4	T_6	T_7'	T_7	MEP	FINAL MEP
C-2	960	480	6.85	3.15	150	149	137	138	11.30	
			6.85	3.15	150	149	137	138	11.30	
			6.85	3.15	150	150	137	138	11.30	11.30
C-3	1440	720	6.60	3.40	151	149	147	148	12.20	
			6.60	3.40	150	149	148	149	12.20	
			6.60	3.40	150	149	149	150	12.20	12.20
C-4	1920	960	6.40	3.60	150	149	162	163	12.90	
			6.40	3.60	146	146	162	163	12.90	
			6.40	3.60	148	146	164	166	12.90	
			6.40	3.60	150	149	164	166	12.90	12.90
C-5	2400	1200	6.10	3.90	150	148	176	178	14.30	
			6.20	3.80	150	149	176	178	13.60	
			6.20	3.80	150	149	176	178	13.60	13.60
C-6	2880	1440	6.00	4.00	150	150	185	187	14.35	
			6.10	4.00	150	150	185	187	14.00	
			6.10	3.90	150	150	185	187	14.00	14.00
C-7'	3120	1560	6.00	4.00	150	149	190	192	14.35	
			6.00	4.00	150	150	190	192	14.35	
			6.00	4.00	150	150	190	192	14.35	14.35

23 APRIL 1951

RUN	RPM	S	h'	h	T_4	T_6	T_7'	T_7	MEP	FINAL MEP
C-1	480	240	7.50	2.50	153	150	113	114	8.97	
			7.60	2.40	151	150	115.5	117	8.61	
			7.60	2.40	150	148	118	119	8.61	
			7.65	2.35	150	148	118.5	120	8.44	
			7.65	2.35	150	148	119.0	120	8.44	8.44

NOTE: C-7' MAXIMUM SPEED RUN   h' SCALE ZERO AT 10.0

TABLE VI

4" G.S. ENGINE

A CONDITION – COMPLETE ENGINE

$T_1 = 180°F$ $T_4 = 150°F$

13 MAY 1951

RUN	RPM	s	d'	d	h'	h	T_1	T_2	T_4	T_6	T_7	MEP	FINAL MEP
A-3	900	720	-2.0	6.0	3.8	6.2	178	178	148	149	154	20.4	
			-2.0	6.0	4.0	6.0	178	178	150	149	158	19.7	
			-2.0	6.0	4.0	6.0	178	178	146	146	158.5	19.7	
			-2.0	6.0	4.1	5.9	180	180	150	150	158	19.35	19.35
A-4	1200	960	-2.0	6.0	3.2	6.8	180	180	150	150	171	22.3	
			-2.0	6.0	3.2	6.8	181	181	151	150	172	22.3	
			-2.0	6.0	3.3	6.7	181	181	150	150	173	22.0	
			-2.0	6.0	3.6	6.4	180	180	150	150	173	21.0	
			-2.0	6.0	3.4	6.6	180	180	150	150	173	21.6	21.60
A-5	1500	1200	-2.0	6.0	2.7	7.3	180	180	150	150	188	23.95	
			-2.0	6.0	2.8	7.2	180	180	152	152	188.5	23.6	
			-2.0	6.0	2.8	7.2	180	180	150	150	188.5	23.6	23.60
A-6	1800	1440	-2.0	6.0	2.0	8.0	180	180	151	151	202	26.25	
			-2.0	6.0	2.0	8.0	180	180	150	150	202	26.25	26.25
A-7	2100	1680	-2.0	6.0	1.0	9.0	180	180	154	154	208	29.5	
			-2.0	6.0	1.5	8.5	180	180	154	154	210	27.9	
			-2.0	6.0	1.5	8.5	180	180	154	154	210	27.9	
			-2.0	6.0	1.5	8.6	180	180	154	154	210.5	27.9	27.90
A-2	600	480	-2.0	6.0	4.5	5.5	178	178	148	148	153	18.0	
			-2.0	6.0	4.5	5.5	180	180	150	150	153	18.0	
			-2.0	6.0	4.5	5.5	181	181	150	150	153.5	18.0	18.00
A-1	300	240	-2.0	6.0	5.6	4.4	181	181	150	150	143.0	14.4	
			-2.0	6.0	5.6	4.4	181	181	150	150	143.0	14.4	14.40

d' SCALE ZERO AT -8.0

h' SCALE ZERO AT 10.0

TABLE VII

4" G. S. ENGINE

B CONDITION – CRANKSHAFT, ROD, AND PISTON

$T_1 = 180°F$ $T_4 = 150°F$

28 MARCH 1951

RUN	RPM	s	d'	d	h'	h	T_1	T_2	T_4	T_6	T_7	MEP	FINAL MEP
B-4	1200	960	-2.5	5.5	4.0	6.0	173	173	149	148	174	19.7	
			-2.5	5.5	4.3	5.7	178	178	151	151	175	18.7	
			-2.5	5.5	4.5	5.5	179	179	146	147	176	18.0	
			-2.5	5.5	4.7	5.3	180	180	154	154	176.5	17.4	
			-2.5	5.5	5.0	5.0	182	182	150	150	177.5	16.4	
			-2.5	5.5	5.0	5.0	182	182	150	150	178.5	16.4	
			-2.5	5.5	5.0	5.0	181	181	150	150	178.5	16.4	16.4
B-3	900	720	-2.5	5.5	5.6	4.4	179	179	150	160	166	14.45	
			-2.5	5.5	5.6	4.4	180	180	150	160	166	14.45	14.45
B-2	600	480	-2.5	5.5	6.2	3.8	180	180	150	150	157	12.48	
			-2.5	5.5	6.1	3.9	180	180	148	149	156.5	12.80	
			-2.5	5.5	6.1	3.9	181	181	150	150	156.5	12.80	12.80
B-1	300	240	-2.5	5.5	7.0	3.0	180	180	150	150	148	9.85	
			-2.5	5.5	6.9	3.1	181	180	150	149	147	10.20	
			-2.5	5.5	6.9	3.1	181	180	150	150	146	10.20	10.2
B-6	1800	1440	-2.5	5.5	4.5	5.5	180	180	150	150	192	18.0	
			-2.5	5.5	4.2	5.8	180	180	150	150	197	19.1	
			-2.5	5.5	4.2	5.8	180	180	150	150	198	19.1	
			-2.5	5.5	4.2	5.8	180	180	150	149	198	19.1	19.1
B-5	1500	1200	-2.5	5.5	5.1	4.9	180	180	157	156	192.5	16.1	
			-2.5	5.5	5.0	5.0	181	181	150	150	189	16.4	
			-2.5	5.5	4.9	5.1	181	181	150	150	190	16.72	
			-2.5	5.5	4.9	5.1	181	181	150	150	190	16.72	16.72

d' SCALE ZERO AT -8.0

h' SCALE ZERO AT 10.0

TABLE VIII
4" G.S. ENGINE
C CONDITION - CRANKSHAFT AND IDLER
T_1 = 160°F T_4 = 150°F

2 MARCH 1951

RUN	RPM	S	h'	h	T_4	T_6	T_7	MEP	FINAL MEP
C-4	1200	960	7.15	2.85	152	149	169	9.35	
			7.15	2.85	152	150	169	9.35	
			7.15	2.85	150	149	169	9.35	9.35
C-5	1500	1200	7.00	3.00	150	148	178	9.85	
			6.95	3.05	151	150	178	10.00	
			7.00	3.00	150	149	179	9.85	9.85
C-6	1800	1440	7.00	3.00	152	152	191	9.85	
			7.00	3.00	152	152	191	9.85	
			7.00	3.00	150	150	191	9.85	9.85
C-1	300	240	8.15	1.85	150	146	132	6.06	
			8.15	1.85	150	146	132	6.06	6.06
C-2	600	480	7.40	2.60	150	146	142	8.54	
			7.40	2.60	152	145	142	8.54	
			7.40	2.60	152	146	142	8.54	8.54
C-3	900	720	7.10	2.90	150	146	154	9.52	
			7.20	2.80	150	146	155	9.20	
			7.20	2.80	150	146	155.5	9.20	9.52
C-7	2100	1680	6.85	3.15	148	148	200.5	10.32	
			6.85	3.15	150	148	200.5	10.32	
			6.85	3.15	150	150	200.5	10.32	10.32
								3 MARCH 1951	
C-5	1500	1200	7.00	3.00	149	148	176	9.85	
			7.00	3.00	150	149	176.5	9.85	
			7.05	2.95	150	149	176.5	9.70	9.85 CHECKS
C-7	2100	1680	7.00	3.00	150	149	198	9.85	
			7.00	3.00	150	149	198	9.85	9.85 CHECKS

h' SCALE ZERO AT 10.0

TABLE IX

6 " G.S. ENGINE

A CONDITION – COMPLETE ENGINE

$T_1 = 180°F$ $T_4 = 150°F$

20 APRIL 1951

RUN	RPM	s	d	h'	h	T_1	T_2	T_4	T_6	T_7	MEP	FINAL MEP
A-2	400	480	6.3	5.10	4.90	181	181	149	150	156	19.10	
			6.3	5.20	4.80	181	181	149	151	156	18.75	18.75
A-3'	700	840	6.3	4.60	5.40	180	180	150	153	172	21.00	
			6.3	4.60	5.40	180	180	150	152	173	21.00	
			6.3	4.60	5.40	180	180	150	152	173	21.00	21.00
A-5	1000	1200	6.3	4.00	6.00	180	180	149	150	192	23.40	
			6.3	4.00	6.00	180	180	149	150	192	23.40	
			6.3	4.00	6.00	180	180	149	150	193	23.40	23.40
A-6'	1300	1560	6.3	3.20	6.80	180	180	150	151	207	26.50	
			6.3	3.40	6.60	180	180	150	151	210	25.70	
			6.3	3.40	6.60	180	180	150	151	211	25.70	25.70
A-7	1400	1680	6.3	3.10	6.90	180	180	151	151	215	26.80	
			6.3	3.00	7.00	180	180	152	152	215	27.20	
			6.3	3.10	6.90	180	180	154	154	215	26.80	26.80
								1 MAY 1951				
A-1	200	240	6.3	5.60	4.40	180	180	165	165	126	17.10	
			6.3	5.60	4.40	182	182	150	150	126	17.10	
			6.3	5.60	4.40	181	181	150	150	127	17.10	17.10

NOTE: A-3' ENGINE HUNTED AT 600 RPM

A-6' ENGINE HUNTED AT 1200 RPM

h' SCALE ZERO AT 10.0

TABLE X

6" G.S. ENGINE

B CONDITION - CRANKSHAFT, ROD, AND PISTON

$T_1 = 180°F$ $T_4 = 150°F$

6 APRIL 1951

RUN	RPM	S	d	h'	h	T_1	T_2	T_4	T_6	T_7	MEP	FINAL MEP
B-3	600	720	6.3	6.50	3.50	180	180	150	152	178	13.6	
			6.3	6.60	3.40	182	182	150	152	177	13.22	
			6.3	6.50	3.50	180	180	150	152	177	13.6	
			6.3	6.50	3.50	180	180	149	151	182	13.6	13.6
B-4	800	960	6.3	6.15	3.85	178	178	148	148	187	15.0	
			6.3	6.40	3.60	182	182	153	154	187	14.0	
			6.3	6.40	3.60	182	182	150	150	187	14.0	14.0
B-5	1000	1200	6.2	6.10	3.90	180	180	150	150	198	15.18	
			6.3	6.10	3.90	180	180	150	151	198	15.18	
			6.3	6.10	3.90	180	180	150	152	198	15.18	15.18
B-6	1200	1440	6.3	5.70	4.30	180	180	150	151	208	16.7	
			6.3	5.70	4.30	180	180	150	151	208	16.7	16.7
B-3	600	720	6.3	6.80	3.20	175	175	150	153	180	12.45	
			6.3	6.75	3.25	180	180	150	153	178	12.65	12.65
B-2	400	480	6.3	7.10	2.90	180	180	149	151	168	11.3	
			6.3	7.10	2.90	180	180	151	152	167	11.3	
			6.3	7.10	2.90	180	180	150	151	167	11.3	11.3
B-1	200	240	6.2	7.70	2.30	182	182	150	153	158	8.95	
			6.3	7.60	2.40	182	182	150	153	152	9.32	
			6.3	7.50	2.50	180	180	150	152	151	9.72	
			6.3	7.50	2.50	180	180	150	152	149	9.72	9.72

h' SCALE ZERO AT 10.0

TABLE XI

6" G.S. ENGINE

C CONDITION – CRANKSHAFT AND IDLER

$T_1 = 180°F$ $T_4 = 150°F$

21 MARCH 1951

RUN	RPM	S	h'	h	T_4	T_6	T_7	MEP	FINAL MEP
C-1	200	240	7.85	2.15	150	150	145	8.35	
			7.85	2.15	152	152	146	8.35	
			7.90	2.10	152	152	146	8.16	
			7.90	2.10	151	152	146.5	8.16	
			7.90	2.10	152	151	147	8.16	8.16
								23 MARCH 1951	
C-2	400	480	7.50	2.50	150	150	159	9.72	
			7.50	2.50	150	150	159	9.72	9.72
C-3'	700	840	7.20	2.80	151	151	172	10.90	
			7.20	2.80	151	151	172	10.90	
			7.20	2.80	150	150	172	10.90	10.90
C-4	800	960	7.10	2.90	150	150	177	11.29	
			7.10	2.90	150	150	177	11.29	
			7.10	2.90	150	150	177.5	11.29	11.29
C-5	1000	1200	6.95	3.05	150	150	187	11.77	
			6.95	3.05	150	150	187	11.77	11.77
C-6'	1300	1560	6.65	3.35	150	150	201	13.00	
			6.65	3.35	150	150	201	13.00	13.00
C-7	1400	1680	6.60	3.40	150	150	207	13.20	
			6.60	3.40	150	150	206.5	13.20	13.20
C-2	400	480	7.50	2.50	150	150	159.5	9.72	CHECK
C-1	200	240	7.90	2.10	150	150	149	8.16	CHECK

NOTE: C-3' ENGINE HUNTED AT 600 RPM

C-6' ENGINE HUNTED AT 1200 RPM

h' SCALE ZERO AT 10.0

APPENDIX

APPENDIX "A"

G. S. ENGINES

Actual and Relative Sizes

Actual bore	2.500"	4.000"	6.000"	
Relative bore	1.000	1.600	2.400	
Stroke	3.000"	4.800"	7.200"	
Displacement Vol.	14.726 $in.^3$	60.318 $in.^3$	203.57 $in.^3$	
Connecting Rod Length	5.406"	8.650"	12.974"	
Crank radius / Con. rod length	0.2775	0.2775	0.2775	
Piston speed	(0.5)(rpm)	(0.8)(rpm)	(1.2)(rpm)	ft/min.

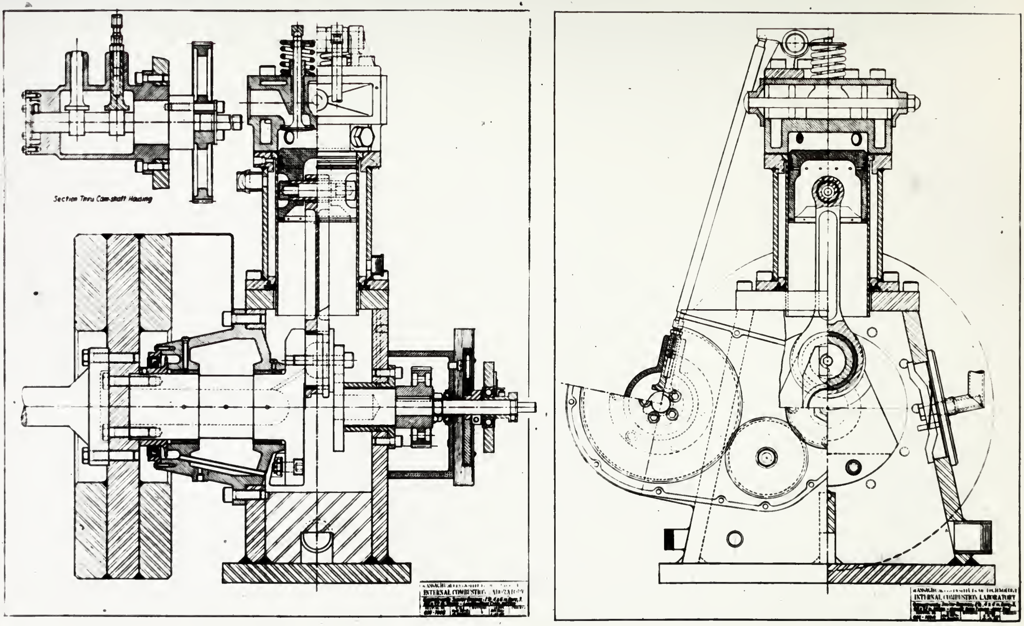
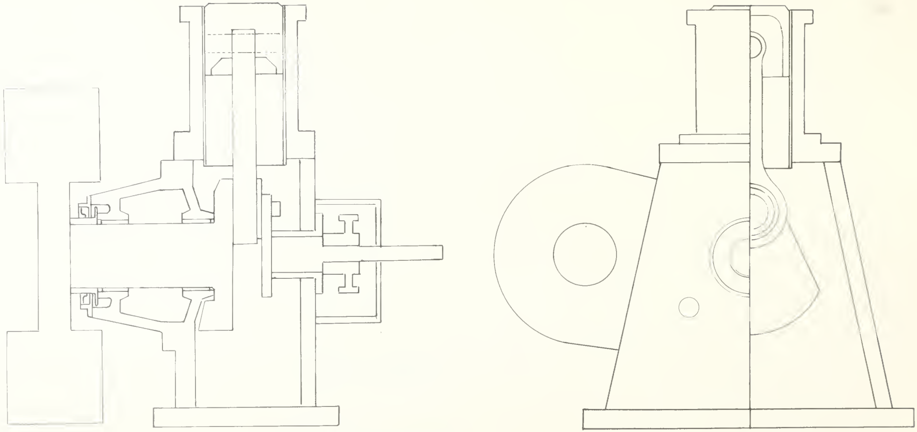


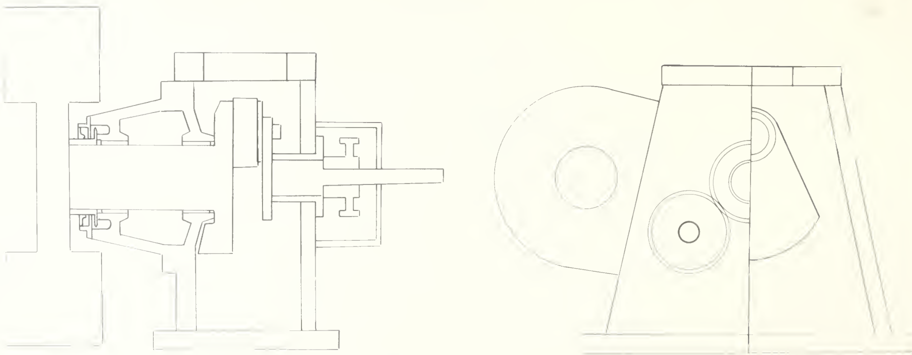
Fig. A-1

"A" CONDITION OF ASSEMBLY



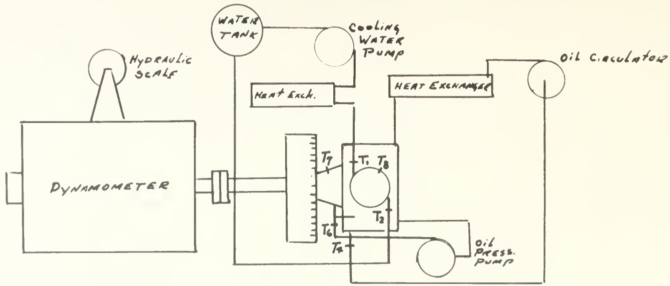
"B" CONDITION OF ASSEMBLY

FIG. A-2



"C" CONDITION OF ASSEMBLY

FIG. A-3



SCHEMATIC DIAGRAM
GEOMETRICALLY
SIMILAR ENGINES
FIG. A-4

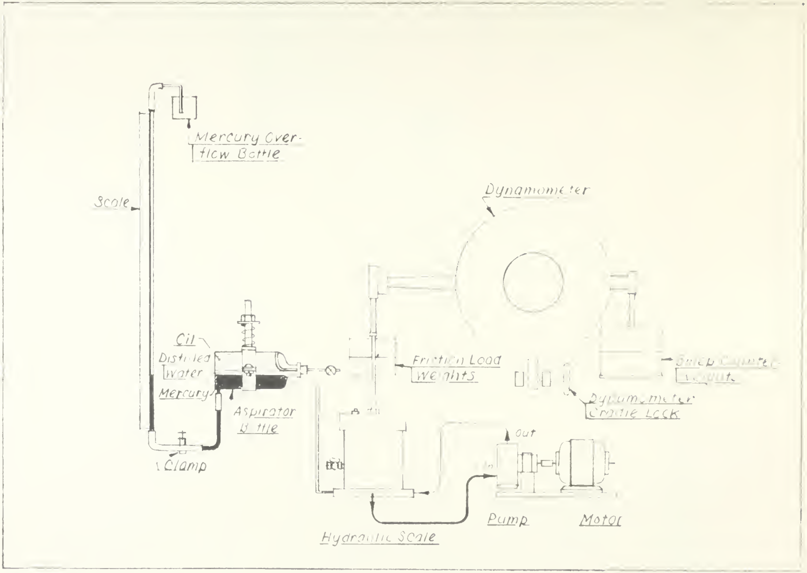


FIG. A-V
Schematic Diagram of Hydraulic Scale Installation

APPENDIX "B"

FRICTION THEORY FOR GEOMETRICALLY SIMILAR ENGINES (7)

1.) Viscous Friction

Using Petroff's Derivation for thick Film Lubrication:

$$FHP = K \frac{D}{C} \frac{L}{D} \mu N^2 D^3$$

In a Geometrically Similar System

$$\frac{D}{C} = \text{Constant}$$

$$\frac{L}{D} = \text{Constant}$$

$$\therefore \quad FHP \sim \mu N^2 D^3$$

$$FHP \sim FMEP\, V_d N \sim FMEP\, l^2\, s$$

$$\therefore \quad FMEP \sim \frac{\mu}{l}\, s$$

A ⌖ the same piston speed

$$FMEP \sim \frac{\mu}{l}$$

2.) Coulomb Friction

$$FMEP \sim f\, \frac{(\text{Load Pressure})\, l^2 \cdot l}{V_d} \sim f\, (\text{Load Pressure})$$

The friction factor depends on surface finish and materials which should be the same in similar engines. Also in similar engines IMEP (or Load Pressure) is the same at same piston speed. Therefore, for similar engines operating at the same piston speed the Coulomb FMEP should be the same.

APPENDIX C

LUBRICANTS

In order to meet the similitude requirement that $\mu/1$ be the same for G.S. Engines, the viscosity of the oil used in each engine was adjusted by blending SAE 20 and SAE 60 lubricants in the proper quantities. The oils used had the properties listed in the following table.(1)

	Viscosity s.s.u.			
Engine	100°F.	130°F.	210°F.	Gravity
2½"	349	160.3	52.8	.88
4"	828	339.0	76.2	.89
6"	1665	627.0	114.1	.90

Composition:

2½"	URSA P 20 (Texaco symbol)
4"	54% URSA P 60, 46% P 20 (By volume)
6"	95% URSA P 60, 5% P 20 " "

These oils are a straight mineral oil, wholly paraffin base, distilled, with no additives. The above samples give the same value of $\mu/1$ at 250°F. This temperature was adopted in Ref. 1 as an attempt to satisfy similitude requirements in all parts of the engine.

APPENDIX "D"

WATER FLOW MEASUREMENTS

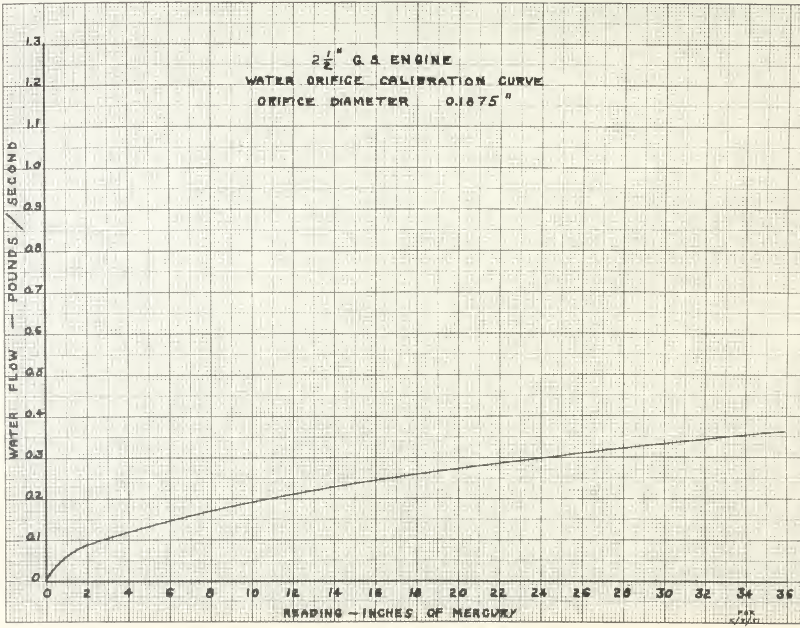
The water flows were measured by means of ASME square edged orifices inserted in the line between the engine outlet and the water expansion tanks. The flow was controlled by a throttle valve inserted on the discharge side of the water pumps.

Each orifice was calibrated and the results plotted in Figs. D-1, D-2, and D-3.

The flow rates actually used were:

2"	4"	6"
0.15#/sec.	0.334#/sec.	0.864#/sec.

These flows were based on $0.024^{\#}/\text{sec.}/\text{in}^2$ for all engines.



2 1/2" G. S. ENGINE
WATER ORIFICE CALIBRATION CURVE
ORIFICE DIAMETER 0.1875"
WATER FLOW — POUNDS / SECOND
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
READING — INCHES OF MERCURY

FIG. D-1

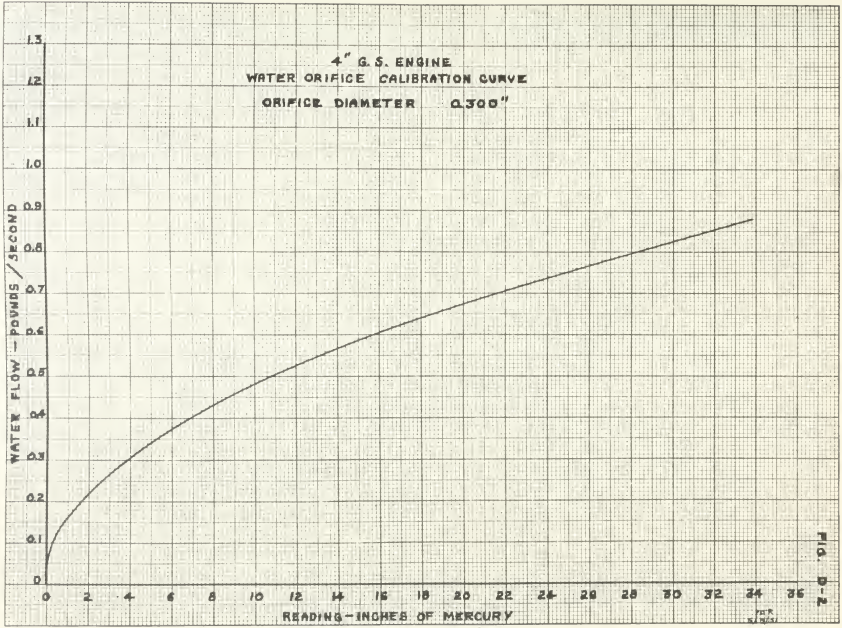

4" G.S. ENGINE
WATER ORIFICE CALIBRATION CURVE
ORIFICE DIAMETER 0.300"
WATER FLOW — POUNDS / SECOND
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
READING—INCHES OF MERCURY

FIG. D-2

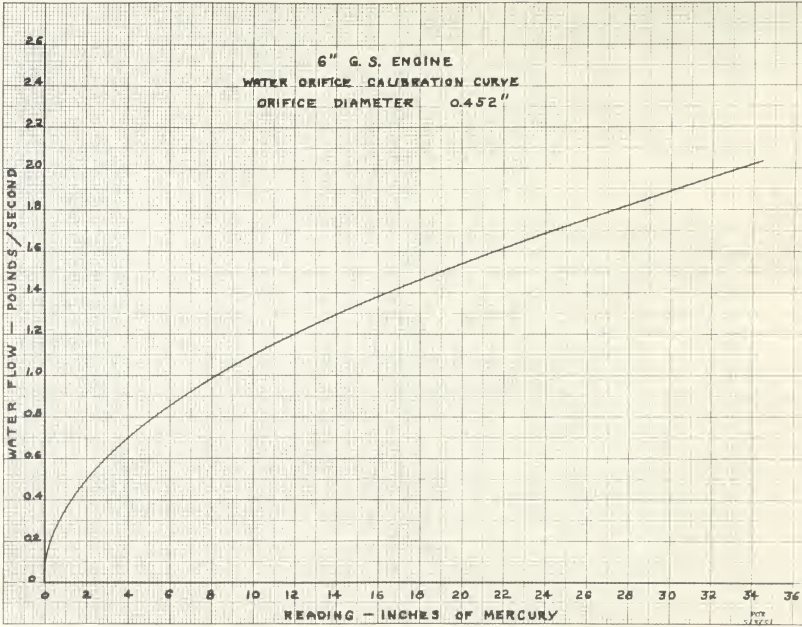

6" G. S. ENGINE
WATER ORIFICE CALIBRATION CURVE
ORIFICE DIAMETER 0.452"
WATER FLOW — POUNDS/SECOND
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
READING — INCHES OF MERCURY

FIG. D-[illegible]

APPENDIX "E"

MEASURED DIMENSIONS, G.S. ENGINES

Engine	2½"	4" *	6"	Remarks
Main Bearing (Crankside)	2.1195"	3.3898"	5.0850"	New Bronze bearings
Crankshaft	2.1170"	3.3850"	5.0790"	on 2½" engine
Clearance	.0025"	0.0048"	0.0060"	
Clearance/Bore	0.0010	0.0012	0.0010	
Main Bearing (Flywheel)	2.1195"	Not observed	5.085"	New bronze bearing
Crankshaft	2.1170"	"	5.079"	On 2½" engine
Clearance	0.0025"	"	0.006"	
Clearance/Bore	0.0010	"	0.0010	
ConRod Bearing (Large end)	1.6291"	2.614"	3.904"	New bronze conrod
Crankpin Journal	1.6268"	2.610"	3.899" **	bearing on 2½"
Clearance	0.0023"	0.004"	0.005"	engine
Clearance/Bore	0.00092	0.001	0.000835	
Camshaft Bearing (Gear end)	Not observed	Not observed	3.373"	
Journal	"	"	3.371"	
Clearance	"	"	0.004"	
Clearance/Bore			0.00066	
Camshaft Bearing (Fly-wheel end)	Not observed	Not observed	1.500"	
Journal	" "	" "	1.498"	
Clearance	" "	" "	0.002"	
Clearance/Bore			0.00033	

* Data in this column not observed by authors but supplied from records of Prof. W. A. Leary of Sloan Laboratory.

** Laboratory records show this dimension to be 3.8982" which would make Clearance/Bore 0.00097

MEASURED PISTON RING DIAMETRICAL TENSIONS

Engine	2½"	4"	6"
Top Compression Ring	950 Gms	2725 Gms	4585 Gms
Tension/Bore^2	148.9	170.0	127.0
Lower Compression Ring	970 Gms	2700 Gms	5675 Gms
Tension/Bore^2	147.0	168	158
Oil Ring	1325 Gms	2900 Gms	7575 Gms
Tension/Bore^2	215.0	185.0	216.0

APPENDIX "F"

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